



STUDIES IN CEREAL DISEASES

IV

STEM RUST IN WESTERN CANADA

By

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STEM RUST IN WESTERN CANADA

By D. L. BAILEY*

ECONOMIC IMPORTANCE

Little need be said to emphasize the economic importance of stem rust of cereals in Western Canada. Persistently recurring rust losses have fixed public attention on the matter, and stem rust is accepted to-day as the most serious problem in wheat production in Manitoba and Saskatchewan. The most serious epidemic on record occurred in 1916 and caused an estimated loss in Western Canada of \$200,000,000, through injury to the wheat crop alone. In 1923 another epidemic occurred which was not, however, nearly so disastrous as the one in 1916, largely because a much smaller area was involved. In that year, Manitoba and the adjoining southern and eastern sections of Saskatchewan suffered a loss of at least \$75,000,000 from rust. In 1927, still another epidemic occurred which was comparable with the one of 1916 in severity and scope and in the damage done. Unfortunately, rust losses have not been confined to these epidemic years. Many sections of Manitoba and Southern Saskatchewan have suffered from rust to a greater or less extent every year during the last ten years. In these districts the farmers can no longer grow hard red spring wheats with profit, and consequently there has been an enormous increase in the production of intrinsically less valuable crops like durum wheats and barley. The average annual loss from stem rust during the last twenty crops years has been in the neighbourhood of twenty-five million dollars. These actual losses, coupled with the uncertainty of production and other incidental disturbing factors, combine to create a situation which demands the solution of the rust problem with the greatest despatch, if the future of cereal production in Western Canada is to be assured.

CAUSE OF RUST

LIFE-HISTORY AND DEVELOPMENT OF *Puccinia graminis*

Although the rust problem itself is older far than agricultural history, accurate and adequate information regarding the cause of rust is recent indeed. The ancient Hebrews knew rust and their prophets regarded it as an act of God punishing the children of Israel for their short-comings. The Romans feared rust no less than we do to-day, and attempted to escape its ravages by elaborate sacrifices to especially created rust gods. Then, for long centuries after mythology was outgrown, mankind speculated as to the cause of rust. Some said it came from the air, some that it came from the soil, while others thought it was merely the external evidence of an internal breakdown of the plant. Everybody was entitled to his opinion because its accuracy was difficult to establish. Finally, about 1600, the compound microscope was developed and later it was definitely established that rust was caused by a living organism. Unfortunately, however, this rust organism had just about the most complicated life history known anywhere in the realm of microbiology, and it was not until 1848 that the distinguished German mycologist, DeBary, gave us the essential skeleton of this life history. Let us consider this life history for a time.

If we take from a rusted plant the smallest bit of red rust which we can place on the point of a knife and magnify this about four hundred times, we shall find this reddish bit of rust is composed of literally thousands of extremely

* Dr. Bailey, since the manuscript of this Bulletin went into the printers' hands, has resigned his position under the Department of Agriculture to accept the chair of Plant Pathology at Toronto University.

small, oval, cinnamon-coloured bodies which appear like so many weed seeds in miniature. The likeness is not misleading, for we are in fact looking at the "seeds" of the microscopic rust plant. These small bodies are called spores. If these spores are given proper conditions of moisture and temperature, they begin to grow within an hour, each spore pushing out a colourless, thread-like germ tube. Unless the germinating spore is in contact with a wheat plant, growth must cease as soon as the food material which is stored in the spore becomes exhausted. If, however, the spore is on a wheat plant, the germ tube grows through a breathing pore and establishes the rust organism within the tissues of the plant. A considerable development of mould-like rust mycelium occurs within infected tissues and at the expense of these tissues, since the fungus depends entirely on the cells among which it is developing for nourishment. These cells are tapped by peg-like processes which withdraw for the use of the fungus the food which should have been utilized in the normal development of the host plant. The rust organism develops thus quietly and inconspicuously, without giving any external indication of its being there, for from five to ten days, depending on weather conditions. At the end of that time, the rust mycelium masses at various places in the infected tissues, produces a new generation of spores, which finally rupture the surface of the leaf or stem and appear as a spot or pustule of rust. Thus a single spore is capable of producing within ten days to two weeks a whole pustule of rust made up of thousands of rust spores. Each of these new spores can develop just as soon as proper conditions of moisture and temperature occur. Since they are so very small and so light, they are ideally adapted to being scattered about by the lightest air currents.

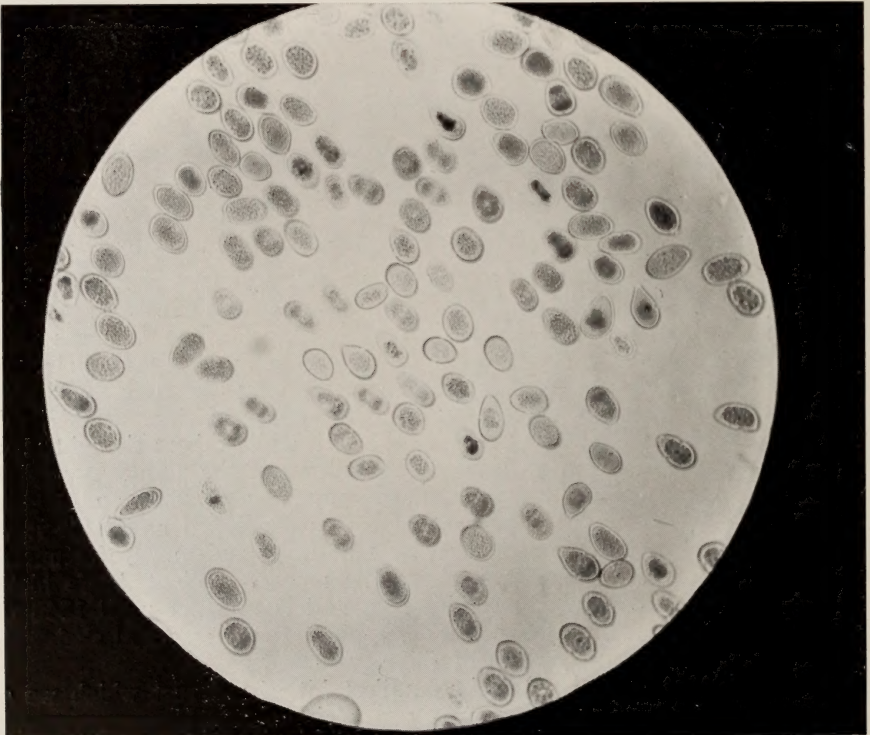


FIG. 1.—Summer spores of the rust fungus *Puccinia graminis* magnified about 400 times. These are also called "red spores" and "urediniospores". These spores germinate as soon after being produced as suitable environmental conditions occur. They reinfect wheat. (Photo—Dr. A. Savage)

The ease with which they are distributed and the enormous number of spores which are produced account in a large measure for the amazingly rapid development and spread of rust when weather conditions are favourable. Rapidly repeating generations of urediniospores, produced in the manner just described, account for the development of the disastrous epidemics which occur in Western Canada.

This cycle repeats itself as long as weather conditions favour rust development or until the crop begins to die or mature. Then a different type of spore is produced. Instead of being thin-walled, oval, and orange-coloured like the summer spores, they are black in colour, have thick walls, are two celled, and are rather like a dumb-bell in shape. The production of these black spores in enormous numbers gives the rusted straw a black appearance, and it is this developmental stage which is so commonly referred to as "black rust." These black spores are the winter spores, or teliospores, and they are evidently designed to tide the rust organism over a season unfavourable to its active development. Like many seeds, they pass through a dormant period and cannot be forced to develop for a long time after they are produced. In Western Canada the black spores are produced in late summer and fall, and do not ordinarily begin to germinate until the following spring. During their dormancy they withstand low temperature without apparent injury. In the spring they develop in a very characteristic way: each cell of the teliospore pushes out a stout tube-like growth, called a promycelium, which soon stops growing however, and lays down cross walls which divide it into four cells. From each of these four cells a very small, colourless, secondary spore is developed on a small projection from the side of the cell. These sporidia, as they are called, are forcibly shot off from

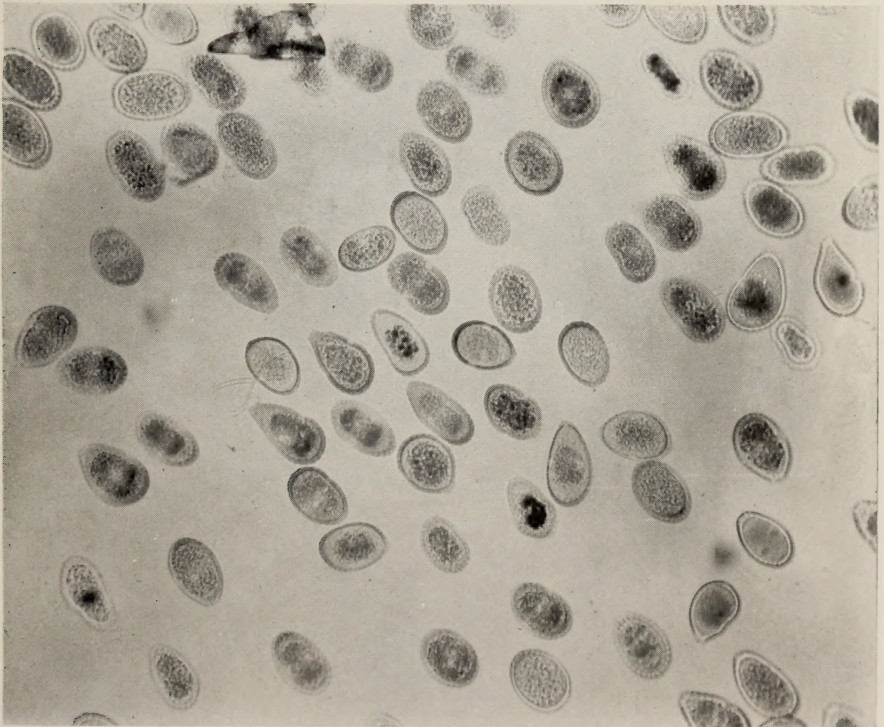


FIG. 2.—Urediniospores as in Fig. 1, but magnified still further. Note the median pores in the spore walls through which the germ tube pushes out when the spore begins to germinate. (Photo—Dr. A. Savage).

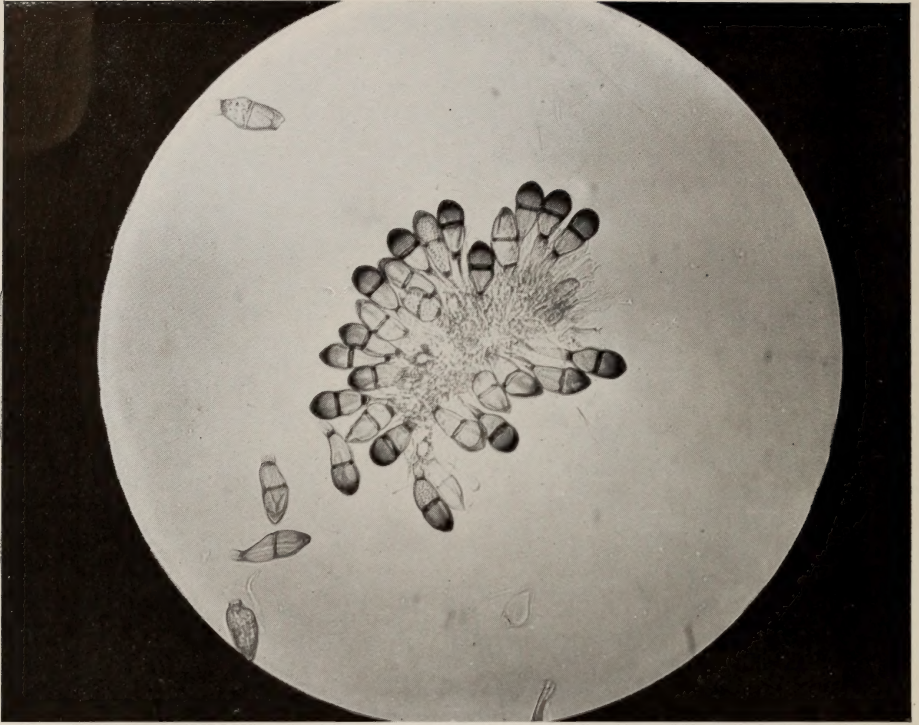


FIG. 3.—Black spores, or teliospores of *Puccinia graminis*. In Western Canada they are produced in late summer and fall, and remain dormant through the winter. The presence of these spores in enormous numbers on rusted straw gives it a black appearance, and accounts for the name "black rust" which is popularly given to this stage. (Photo—Dr. A. Savage).

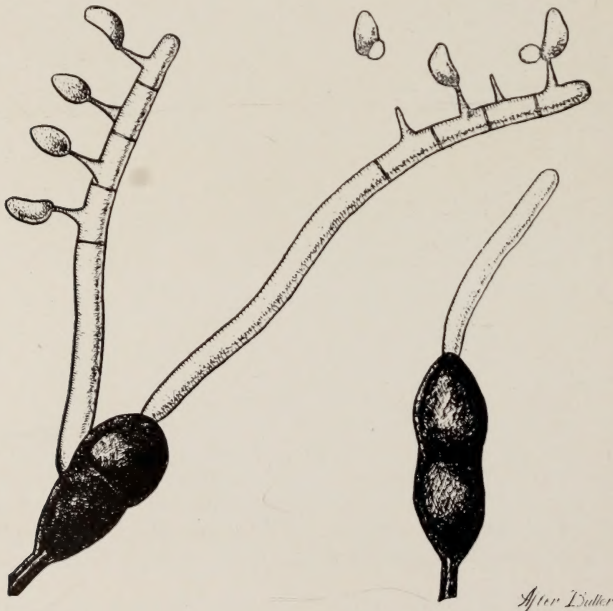


FIG. 4.—Germinating teliospores, showing how the secondary spores or sporidia are produced. In Western Canada, this occurs in early spring. (After Buller).

the projections on which they are produced and so are set free to be scattered about in all directions by the wind. Strangely enough, these spores cannot reinfect wheat, although that is the host on which they would naturally be expected to develop. For a long time their significance was unknown, but European farmers of the early part of the last century furnished the clue. They insisted that, for some reason or other, cereals grown near barberry bushes were always more heavily rusted than the rest.

Following this lead it was readily shown that the sporidia produced by the black spores actually did infect the barberry. As a result of this infection, the infected barberry leaves produced on their upper surfaces enormous numbers of extremely minute, apparently non-functional spores called pycnosporia, which were exuded in a viscous nectar-like liquid. Immediately below these pyrenial spots, on the under side of the leaf, there developed slightly later groups of tiny orange-coloured cup-like structures, the so-called aecia. The orange-coloured contents of these small cups proved to be orange-coloured spores of still another type, the aeciospores. These aeciospores could not attack the barberry but were able to attack wheat, and as a result of this infection the red or summer stage of rust, with its characteristic red spores, was initiated.

This then constitutes the complete life cycle of the rust organism. It is summarized diagrammatically in fig. 9, which indicates the characteristic spore form of each developmental stage with the host which it attacks and the time of the year at which it is produced. Although this life history is so complicated that it sounds at first almost fantastic, a great many rusts other than this one have proved to have a similarly complicated development, and hence this type of life history is accepted as quite commonplace by people working with rusts.

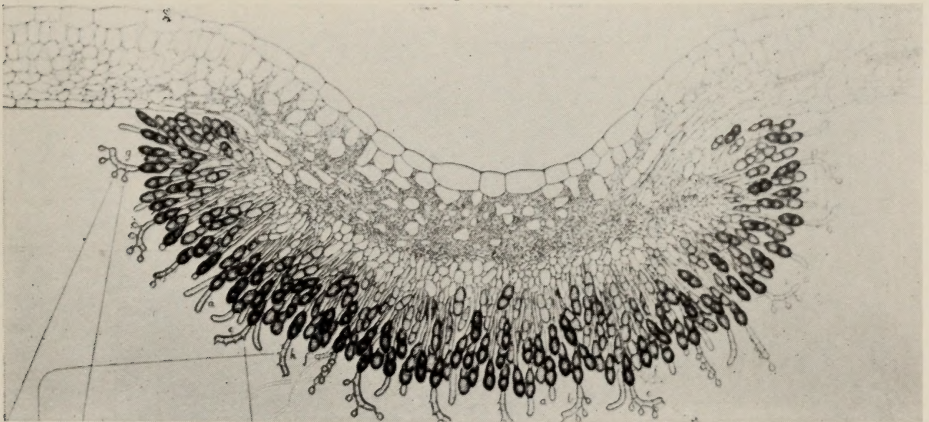


FIG. 5.—Germinating teliospores giving an idea of the enormous number of sporidia which may be produced. The picture represents about one twenty-fifth of an inch of rusted material. These sporidia can infect only the common barberry, *Berberis vulgaris*. (After Buller.)

FACTORS INFLUENCING RUST DEVELOPMENT

Three conditions must be fulfilled before rust development can take place: (1) the rust organism must be present; (2) it must be in contact with a host plant which it can infect; and (3) the environmental conditions must be such that the rust organism can develop and cause infection. Therefore, anything which influences any one of these three factors can reasonably be expected to influence the subsequent development of rust in any given instance. We shall discuss in a later section the factors influencing the number of rust spores which may be present, and so consider here only the influence of environmental conditions and host relations on rust development.



FIG. 6.—The lower surface of two barberry leaves infected with stem rust. Note the abundant development of the cup-like aecia.



FIG. 7.—A single aecial cluster on a barberry leaf greatly enlarged. The cup-like aecia are full of aeciospores which infect cereals and initiate the red stage of rust.

Moisture and temperature are the environmental factors which influence most profoundly rust development. Their influence is so marked and so unmistakable that even careful observers are apt to jump to the conclusion that these weather conditions are the primary cause of rust. But no type of weather will produce rust under controlled conditions where the rust organism is lacking, so the influence must be an indirect one exerted on the rust organism. The truth of this is easily demonstrated. For example, rust spores may be placed on a susceptible wheat plant in great numbers and the plant will never be attacked so long as it is kept dry. Moisture is absolutely essential to the germination of the rust spore and the early stages of infection. A film of moisture must remain on the plant long enough to permit the spore to germinate and the tube which it sends out to penetrate into the interior of the plant. This can be accomplished quite effectively within from nine to twelve hours. Once the fungus is within the plant it is quite independent of moisture on the surface of the plant. This means, therefore, that all the spores present on a wheat plant might successfully infect that plant with no more moisture than would be supplied by an ordinary heavy summer dew.



FIG. 8.—Aeciospores, or the spores which are produced in the aecia, magnified about 400 times. These spores infect cereals and the ordinary red stage with urediniospores results.

Temperature is a limiting factor throughout all stages in rust development. While the red spores can germinate and cause infection through a wide range of temperature, they do so most rapidly and most successfully at relatively high temperatures, from 65° to 75° F. Therefore, the times of most rapid rust development will be those during which a combination of high temperature and high humidity prevail. Occasionally rust seems to develop very rapidly during a hot dry spell. This usually occurs following a moist cool spell, and is explained

as follows. During the moist cool weather an enormous number of rust spores germinated and penetrated within the wheat plants. The low temperatures slowed down subsequent development so much that the fungus remained practically dormant within the host. When the hot weather came the development of these infections was speeded up with the result that a sudden appearance of rust occurred under conditions which would ordinarily not be considered particularly favourable for its development.

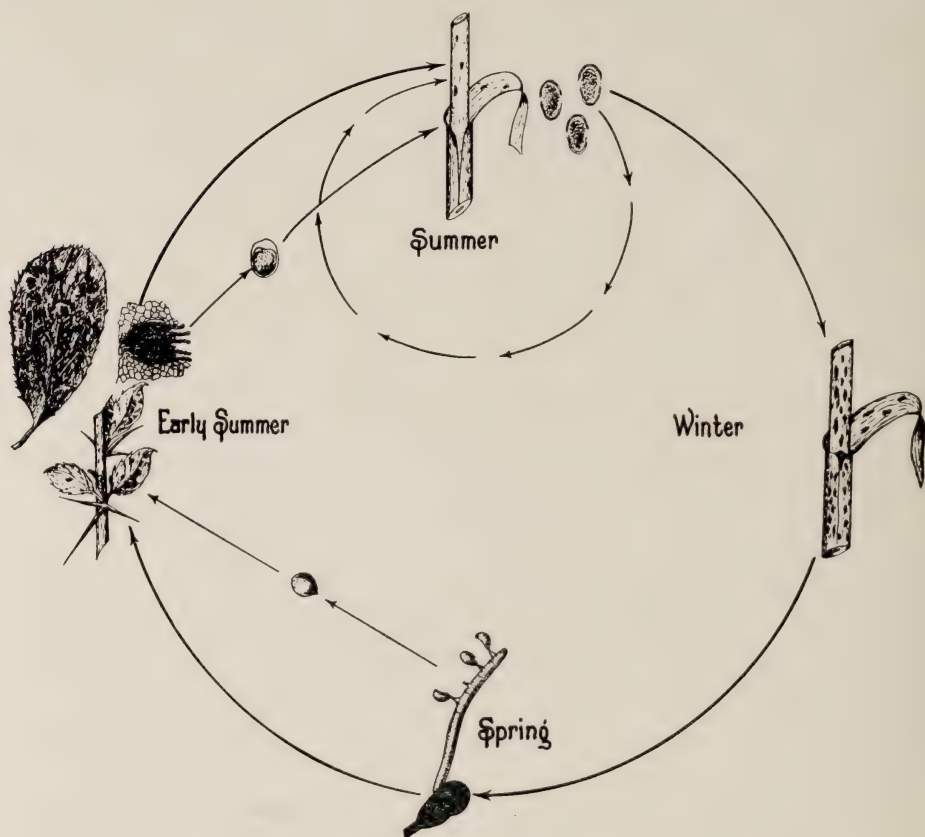


FIG. 9.—Diagrammatic representation of the life cycle of *Puccinia graminis*, the organism causing stem rust. If we begin with the common red or summer stage on wheat, it is characterized by the production of urediniospores which may infect wheat again. This cycle repeats throughout the summer and is followed by the black stage, characterized by the production of black spores or teliospores. These remain dormant until spring and then produce secondary spores, or sporidia, which infect the barberry. The aecial state develops on the barberry, the cup-like aecia being filled with still another type of spore—the aeciospore. The aeciospores cannot infect barberry but infect wheat and initiate again the red or summer stage on it.

Weather conditions likewise seem to modify the structure of the wheat straw and influence somewhat the ease with which it becomes rusted. Rust develops only in the green tissue of the plant so that any factor of the environment which tends to increase the woody strengthening tissues at the expense of the green tissues will give rust that much less chance to develop. The thick, lush growth on summer-fallow is always more heavily rusted than the tough, shorter growth on stubble. This is partly due to differences in the straw, though such factors as air-drainage, and moisture-retention operate as well.

Excessive fertilization² with nitrogen produces a very soft, succulent straw comparable to heavy summer-fallow stands. Excessive phosphates, on the other hand, tend to a firmer, tougher straw. In this way fertilizers may influence the degree of rust development.

Time of maturity greatly influences the degree of rust development; a difference of a week in this respect often saves or ruins a crop. This is simply because the later crop has a greater opportunity to become rusted. It is exposed for a greater length of time than the earlier one, and, moreover, this occurs at a critical period when a few days may greatly increase the number of spores in the air and hence greatly increase the likelihood of infection taking place.

Often, especially when the epidemic is light, rust development is very patchy, even in the same field or in the same district. This is sometimes a reflection of very local fluctuations in dews or showers, or may be due to a scarcity of rust spores, in which case the first infections, instead of being fairly common, are much scattered, and subsequent development takes place from these centres of early infection. In many cases it is impossible, with the present state of our knowledge, to account for these local differences, though a careful study of local conditions frequently reveals some environmental factor which influences either the moisture or temperature of the place in question and explains the anomaly.

THE ORIGIN AND SPREAD OF STEM RUST IN WESTERN CANADA

If we keep clearly in mind the life history of the rust organism (see fig. 9) there appear to be only three possible ways by which the rust organism could persist from one year to another in Western Canada. (1) The black spores, overwintering, may in the spring infect barberries, and these in turn send the rust back to the wheat; or (2) the uredinal stage, either as mycelium or as urediniospores, which infect wheat directly, might survive our winters and start rust directly the following spring, or (3) the inoculum which initiates our earliest field infections may originate in some area outside of Western Canada. These three possibilities have now been fairly thoroughly investigated.

THE ROLE OF BARBERRIES

The barberry (*Berberis vulgaris*) (figs. 10 and 11) fortunately is not a native shrub in Western Canada and has proven so poorly adapted to Western Canadian conditions that it has never been very widely introduced as an ornamental. Wherever it was introduced, however, it rusted quite consistently, except in some exposed locations where it frequently escaped. It was evidently a shrub whose cultivation should not be encouraged in a cereal-producing section, so it was outlawed by an amendment to the Destructive Insect and Pest Act in 1916. This amendment prohibited further distribution of barberries from nurseries, and gave the necessary authority to remove without compensation those which had already been introduced. Following this, the Dominion Department of Agriculture, co-operating with the Agricultural Colleges and Provincial Agricultural Departments of the Prairie Provinces, carried out a fairly extensive barberry survey^{3, 4} to locate and destroy those which had been introduced. It was evident from the records of the local nurseries that this number would

² E. C. Stakman and O. S. Aamodt, The effect of fertilizers on the development of stem rust of wheat. Jour. Agr. Res. 27: 6: 1924.

³ V. W. Jackson, W. P. Fraser & D. L. Bailey. The present status of the barberry eradication campaign in Western Canada. Scientific Agriculture 5: 12: 1925.

⁴ Reports of Dominion Botanist, Dom. of Can. Dept. of Agr. for the years 1926, 1927 and 1928.

not be very formidable. This survey has covered every town and village in Manitoba and Saskatchewan with resurveys for one or two years in the districts where any bushes were found, to ensure their removal. Comparatively little systematic rural survey has been carried on, although a rural survey has been combined each year with the rust and plant disease survey that has been



FIG. 10.—A bush of the Common Barberry, *Berberis vulgaris*. This shrub does not ordinarily reach such a large size in Western Canada. Photo by the courtesy of Dr. E. C. Stakman.



FIG. 11.—A shoot of Common Barberry, *Berberis vulgaris*. It can be identified by the holly-like leaves and the spines which are usually in clusters of three. The berries are borne in large clusters. The Japanese barberry, *Berberis Thunbergii*, is resistant to rust and a safe shrub to grow. It is a low-growing shrub with flowers and berries borne singly, and the spines borne singly rather than in groups of three.

carried on. A systematic survey of 400 square miles,⁵ comprising various soil types and various kinds of settlement, was carried out in 1925 in the older settled districts of Manitoba. Practically no barberries were found and it was evident that a general systematic rural survey was not justified. Such an effort seemed particularly pointless, because a careful study of the districts in which the oldest known plantings were located did not indicate the slightest tendency for the barberry to escape from cultivation and become naturalized in Western Canada.

Judging from the very limited influence which the rusted barberries which were found had on the general rust situation and the negative results following what we believe has been their practical eradication, we must conclude that the barberry has never been an important factor in the rust problem in Western Canada.

⁵ D. L. Bailey in Report of Dom. Bot. Dom. of Can. Dept. of Agr. for the year 1925, p. 67-68. 1926.

OVERWINTERING OF THE UREDINIAL STAGE

Several persons⁶ have investigated during the last ten years the possibility of urediniospores living through the winter and causing infection the following spring. They have found that the percentage of viable spores drops relatively quickly from around 90 per cent in late summer to less than 10 in early winter. This percentage is fairly well maintained throughout the winter, but the alternate freezing and thawing of early spring quickly reduces the percentage of living spores to a mere trace. Usually it is from six weeks to two months after the last viable spores can be located before rust infection begins to show up in the field. Moreover, the first infections usually appear on the spring-sown wheat rather than on the perennial grasses, and this fact does not suggest overwintering urediniospores as the source of our earliest infections. There have, however, been a few cases where a localized, premature development of rust strongly suggested its having overwintered as mycelium or as urediniospores. In general, though, it must be concluded that overwintering of the uredinial stage, either as mycelium or as spores, is the conspicuous exception rather than the rule, if it occurs at all.

THE RUST-SPORE CONTENT OF THE AIR IN WESTERN CANADA IN RELATION TO THE ORIGIN AND SPREAD OF RUST

Since rusted barberries and overwintering of the uredinial stage contribute so little toward the propagation of rust year after year in Western Canada, this negative evidence suggests strongly an outside source of inoculum. This possibility has been investigated by the Dominion Rust Research Laboratory in co-operation with the Dominion Plant Pathological Laboratory at Saskatoon and the Winnipeg wing of the Royal Canadian Air Force. The question has been studied largely by ascertaining the rust-spore content of the air over various

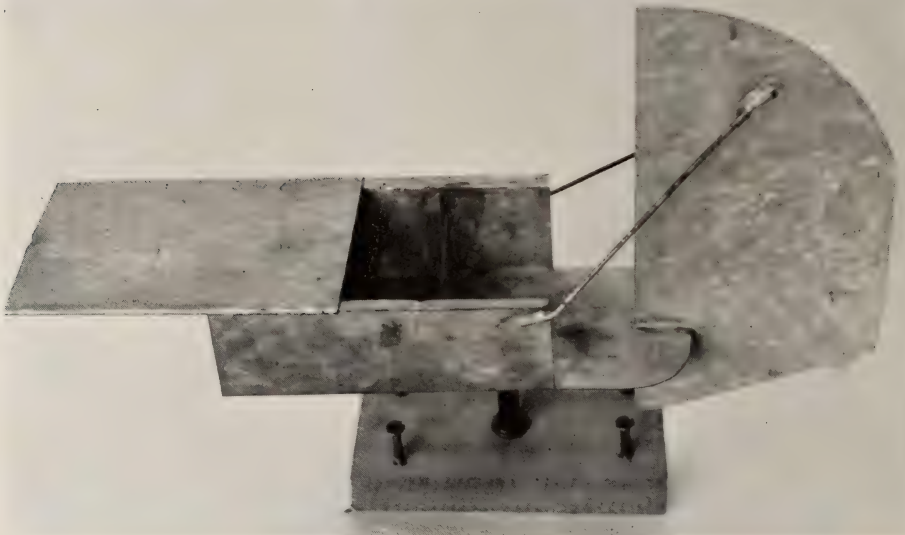


FIG. 12.—Stationary spore-trap. A weather-vane arrangement in which a glass slide lightly smeared with vaseline was kept facing the prevailing wind and protected from rain. The slides were exposed for one or sometimes two days and were then examined under the microscope to determine how many rust spores had been caught.

⁶ See Reports of Dominion Botanist, Dom. of Can. Dept. of Agr. for the years 1916 to 1928.

districts in Western Canada throughout the season, and by making, simultaneously, careful field observations on rust development in these same districts. Two types of spore-trap have been used in studying the spore content of the air.



Fig. 13.—The spore-trap which was exposed from aeroplane along with bottle in which it was shipped to prevent contamination.

The stationary trap (fig. 12) was merely a weather-vane arrangement, on which a small glass slide, 3 by 1 inches, thinly smeared on one side with vaseline, was placed so that this side faced in the direction of the prevailing wind, and at

the same time was protected from rain which might wash the surface of the slide. Spores and small dust particles blown by the wind came in contact with the vaseline and adhered to it. After being exposed for one or sometimes two days, the slide was replaced by a fresh one and the exposed one was sent to the nearest laboratory for examination under the microscope. These stationary traps were located at a number of stations in southern, central, and northern parts of Manitoba, Saskatchewan, and Alberta.

The spore-trap exposed from aeroplanes was slightly different, and is illustrated in fig. 13. To one face of a paddle was attached by means of two parallel grooves a pair of slides which were lightly smeared with vaseline on the exposed surface. The handle of the paddle was passed through a stopper which fitted a bottle large enough to enclose the part of the paddle holding the slides. A paddle thus fitted up was placed in a bottle and tightly corked to prevent any spores gaining access to the bottle. A large number of such bottles were sent to the various Air Force bases. When the pilot made the exposures, the paddle was removed from the bottle and fixed by the handle in a socket on the plane for the duration of the exposure, which was usually from five to fifteen minutes. Then the paddle was replaced in the bottle to prevent any other spores coming in contact with it, and returned to the Winnipeg laboratory. Data regarding the location, altitude, and duration of each exposure accompanied each bottle, together with certain meteorological data as to wind direction, etc.

Experiments of this type have been carried on for the last three years⁷ and a great many interesting and significant results have been obtained. Each year a relatively few rust spores are caught on the slides in Southern Manitoba and Saskatchewan before any rust can be found in the field even after long, careful search. The time at which the first urediniospores are caught on the slides bears a definite relationship to the stage of rust development farther south in the spring-wheat area of the United States. Furthermore, these first spores are usually caught while a moderate to strong southerly wind is blowing, or a short time thereafter. The combined evidence seems to indicate that our earliest rust infections each year in Western Canada are caused by wind-borne urediniospores from farther south.

Once rust becomes established in a district, the rust-spore content of the air over that district rises until quite unbelievable numbers of spores are present, when the epidemic reaches its peak. For instance, as many as 42,000 spores were caught in one day at Winnipeg on two square inches of the glass slide, in August. Likewise 3,500 spores were caught on an equal area during a ten-minute exposure made by aeroplane 5,000 feet above the Winnipeg Beach area. If we can generalize from the number of spores caught on exposed slides to the number that settle to the ground, the following would hold for the Winnipeg district during the relatively severe rust development of 1925. From July 14 to 28, 18 spores fell daily on each square inch of land. These spores were probably wind-carried from the United States, since rust was not to be found locally at that time, and they initiated the epidemic which broke out in this district about the first of August. When this local epidemic broke out, the number of spores jumped rapidly until approximately 1,100 spores fell daily on each square inch of ground surface. That is, the spore shower was 60 times as heavy after the first of August as it was during the 15 days prior to that time.

In Manitoba in 1927 spores first began to appear during the last three days of May and the early part of June. Traces of spores occurred irregularly throughout the month of June. A light shower of spores apparently fell in Southeastern Saskatchewan about the middle of June and again over that area and Southern Manitoba toward the end of the month. The first pustule of rust found in the field was collected in Southern Manitoba on July 6.

⁷ Any person interested in the details of these experiments should consult the Report of the Dominion Rust Research Laboratory in the Report of the Dominion Botanist, Dominion of Canada Dept. of Agriculture, for the years 1925, 1926 and 1927.

The spread of rust is westward and northward across Western Canada following its initial appearance in the south. Here again the spread can be traced in advance of the field appearance by the rust spores caught on stationary traps located throughout Saskatchewan and Alberta. In 1927, for example, in Alberta at none of the five stations at which traps were located were spores found until the last few days of July, which was three weeks after rust could be found in the field in Manitoba and two weeks earlier than it could be found in the field in Alberta. On July 28 and on subsequent dates a few spores were caught on the slide at Beaver Lodge in the Peace River District. A slight trace of rust was found there in the field during the third week of September. This constitutes a record for the northwestern distribution of stem rust. From these studies it seems evident that the limit of the western spread of rust each year is determined largely by whether or not rust spores are produced elsewhere early enough and in sufficient numbers to reach more remote districts soon enough to start an epidemic there before the crop matures. Therefore, rust is to be expected in Alberta only when the crop is late and when rust is abundant in Manitoba and Saskatchewan.

Just how far rust spores can be carried in the air and remain alive is an interesting question, but it is a difficult one to answer, since there is no means of determining the origin of trapped spores. Considerable numbers of viable spores have been caught at altitudes up to 5,000 feet at Norway House, Manitoba, and the indications were that these must have been carried at least 200 miles. From this it is evident that rust spores are not seriously disturbed by long aerial jaunts.

THE CONTROL OF RUST

Briefly stated then, we have to deal in the rust problem with a microscopic plant living parasitically on its cereal hosts, which is ideally adapted to very rapid development and wide spread through the agency of enormous numbers of rapidly developing spores which, because of their microscopic size, are readily and widely distributed by even the gentlest air currents. Therefore, under ordinary conditions, all the above-ground parts of the wheat plant will be subject to the attack of this rust organism whenever conditions of moisture and temperature permit it to develop. Under such circumstances obviously the only satisfactory method of combating rust is the development of resistant varieties of wheat which will thrive in spite of it.

THE DEVELOPMENT OF RUST-RESISTING CEREAL VARIETIES

While the development of resistant varieties presents the ideal method of solving the rust problem, it is an enormously difficult and complicated project. Let us see what it involves.

WHAT CONSTITUTES ADEQUATE RESISTANCE?

In the first place we must know what constitutes adequate resistance and that is a major problem in itself. It has been known for a long time that varieties differed greatly from each other in their reaction to rust, but individual varieties have not always been consistent in their rust-reaction in different localities and in different years, and it is only comparatively recently that the cause of this variation has been understood. Until 1896 stem rust was regarded as an entity and all collections of it were considered identical, regardless of whether they were collected on wheat, oats, barley, rye, or any of the large number of wild grasses on which it occurs. About that time the Swedish plant pathologists, Eriksson and Henning, showed that such was not the case. They

demonstrated that, while stem rust from all these sources appeared identical even under the microscope, there were in reality a number of strains of this rust which differed from each other in the hosts which each could attack. Thus, they found one form of rust which could infect wheat, barley, and a few closely related grasses, but which could not attack oats, rye, or timothy. Similarly there was a form on oats which could not attack wheat or rye. In this way they distinguished the six major forms of stem rust which are listed in table 1.

TABLE I.

THE PHYSIOLOGIC FORMS OF THE STEM RUST ORGANISM, *Puccinia graminis*

<i>Puccinia graminis</i> —1896.....	<i>Puccinia graminis Tritici</i> on wheat and barley, 1916-1928 ¹			Form 1
	" " <i>Secalis</i> on rye			" 2
	" " <i>Phleipratisensis</i> on timothy			" 3
				Form 40
	" " <i>Avenae</i> on oats, 1921-1928 ²			Form 1
	" " <i>Poa</i> on <i>Poa</i> spp.			" 2
	" " <i>Agrostis</i> on <i>Agrostis</i> spp.			" 3
				" 4
				" 5
				" 6

¹ See Stakman & Levine, Minn. Tech. Bul. 8: 1922.² See Bailey, D. L., Minn. Tech. Bul 35: 1925.

Since these forms of rust cannot be distinguished from each other by differences in form, or morphology, and differ only in their infective powers, or physiology, they are called "physiologic forms". In 1916 Stakman, of Minnesota, showed that this specialization in infective powers went still further than Eriksson and Henning had demonstrated. He found that the form of rust which was confined to wheat and barley was in reality a large number of forms which could be separated from each other by their infection capabilities in regard to twelve standard wheat varieties. From 1916 to 1928, forty odd forms of wheat stem rust have been discovered, largely through the efforts of Stakman and Levine and their co-workers. A study of table 2, which shows the reaction of some commonly grown wheats to five forms of rust which have been collected in Canada, will give a clear idea of how these forms differ from each other. For example, form 36 can be distinguished from forms 21 and 19 by Kanred wheat, since it is susceptible to 36 and highly resistant to 21 and 19. Forms 21 and 19 can be separated from each other by Marquis, since it is susceptible to 21 and resistant to 19.

TABLE 2.

THE RUST REACTION OF FOUR WHEAT VARIETIES TO FIVE PHYSIOLOGIC FORMS OF WHEAT STEM RUST.

Physiologic form number	Rust reaction of			
	Marquis	Kota	Kanred	Kubanka
36.....	Susceptible...	Susceptible.....	Susceptible...	Moderately susceptible
21.....	Susceptible...	Susceptible.....	Resistant....	Susceptible
19.....	Resistant....	Moderately susceptible...	Resistant....	Susceptible
3.....	Susceptible...	Susceptible.....	Susceptible...	Resistant
24.....	Susceptible...	Resistant.....	Resistant....	Susceptible

Since these different forms of rust exist which may react quite differently on the same variety of wheat, it is evident that the resistance of any wheat variety must be designated in terms of specific forms of rust. It is not enough to say that a variety is resistant; we must know exactly to which rust forms it is resistant, and to which it is susceptible. Thus, Kanred, which is usually considered resistant, is susceptible to Form 36, and Marquis, which is considered susceptible, is resistant to Form 19. Likewise, before we can choose or develop a wheat variety which will be rust resistant, we must know what forms of rust are likely to occur in the district in which this variety is to be grown. Or, in terms of our own problem, before we can develop a rust resistant variety for Western Canada, we must know what forms of rust are met with in the Prairie Provinces.



FIG. 14.—Greenhouse culture work determining the physiologic forms of rust which occur in Canada. A collection of rust from a different locality is cultured in each booth. Glass partitions cut down drafts without excluding light. The artificial lights are used during December and January when normal light intensity is too low for satisfactory work. To test the resistance of a variety, rust is transferred to ten seedling leaves, they are sprayed with water and then placed in the glass-topped moisture chamber for 48 hours. By this time the rust has established itself within the tissues of the plants and moisture is no longer necessary, so the plants are removed from the moist chamber and returned to the greenhouse bench, to await the development of rust. This occurs within 10 to 18 days depending on the temperature and light.

PHYSIOLOGIC FORMS OF WHEAT STEM RUST IN CANADA

The investigation of this phase of the problem was begun for the Dominion Department of Agriculture first by Prof. W. P. Fraser at the Dominion Plant Pathological Laboratory at Saskatoon in 1919, and carried on by him until 1925, when it was transferred to the Dominion Rust Research Laboratory at Winnipeg, where it has been continued. During these years an enormous number of collections of stem rust, especially from Western Canada, have been grown in the greenhouse, and the reaction of a large number of wheat varieties to them has been determined. Twenty-five different forms of rust have been found

during those nine years. ⁸, ⁹ Most of these forms were the same as those which Stakman and Levine have found occurring at the same time in the Northern United States. A few forms, five in all, have been found which appear different from any which have been reported to date from the United States.

Tables 3 and 4 give a list of the different forms of rust which have been collected each year, and the places where they were collected. As is shown in these tables, different forms predominated in different years and in different localities. No satisfactory explanation can be advanced to account for one or two forms predominating in a given year, nor for these changing from year to year. It may be merely that those forms which arrive first, or are present to the greatest extent in the early spore showers, get a start over the later-arriving forms. Or, the particular wheat varieties grown south of us and throughout Western Canada may be responsible for some forms multiplying more rapidly than others. The subject is one of the many on which we must have more information before we can make any positive statements.

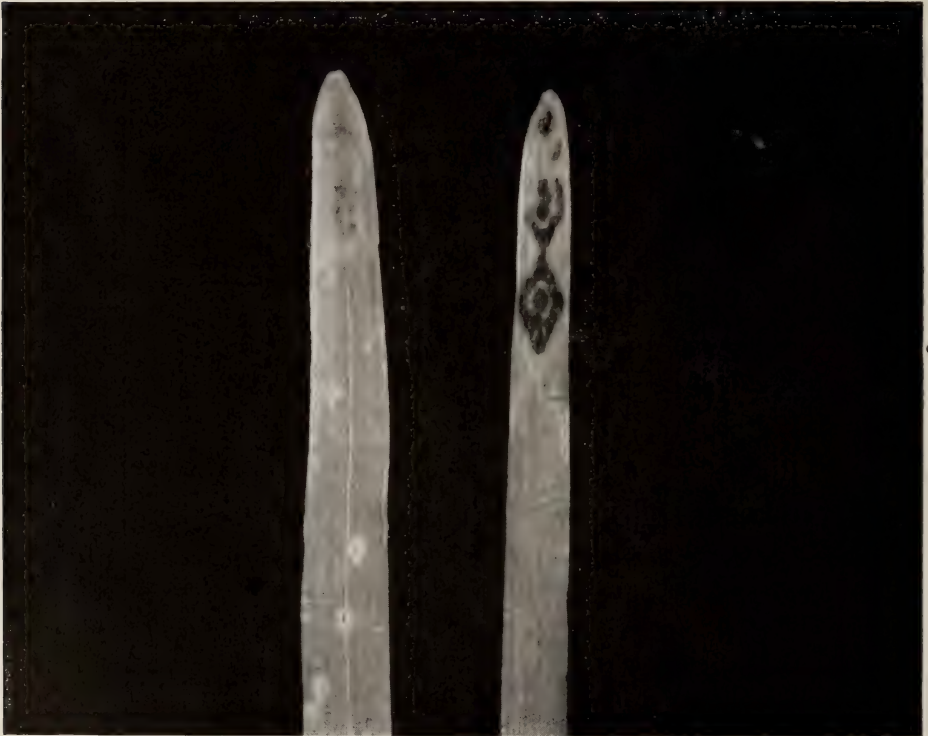


FIG. 15.—The reaction of a resistant and a susceptible variety of wheat to the same form of rust. The leaf on the right developed large healthy pustules and was evidently susceptible. The leaf on the left was resistant. It developed only very small pustules each of which was surrounded by dead leaf tissue which prevents further development or spread of the rust.

THE REACTION OF STANDARD WHEAT VARIETIES TO THE FORMS OF RUST WHICH OCCUR IN CANADA

A large number of greenhouse tests have been carried out to determine the reaction of standard and newly-developed wheat varieties to those forms of rust

⁸ Newton Margaret and T. Johnson. Physiologic Forms of Wheat Stem Rust in Western Canada. *Scientific Agr.* 7: 5: 158-161. 1927.

⁹ ———. Physiologic Forms of Wheat Stem Rust in Western Canada. In *Report of Dominion Rust Research Laboratory, for 1927, 1928.*

which occur most commonly in Western Canada. These tests have been supplemented by field nursery trials, which have compared the rust reaction of a number of varieties in many different localities. In general, these results^{10, 11, 12} indicate that none of our good standard wheat varieties are resistant to even the most commonly occurring forms of rust. It is evident, however, that among some of the newly-developed varieties, like Marquillo, H-44-24, Parker's Selection, and Axminster, there do exist varying amounts of resistance.

TABLE 3.

ANNUAL OCCURRENCE OF PHYSIOLOGIC FORMS OF *Puccinia graminis Tritici* IN CANADA FROM 1919 TO 1926 WITH RECORD OF NUMBER OF TIMES EACH FORM WAS COLLECTED ANNUALLY. M. NEWTON, T. JOHNSON AND A. M. BROWN, IN REPORT OF DOMINION RUST RESEARCH LABORATORY FOR 1927.

Year	Number of times form was collected							
	1919	1920	1921	1922	1923	1924	1925	1926
Form 1.....	2	1	—	—	—	—	—	—
2.....	—	—	—	—	1	—	—	—
3.....	—	4	3	10	10	16	—	—
9.....	4	6	2	3	—	—	—	1
11.....	2	5	2	3	5	9	—	—
12.....	—	2	—	—	—	5	—	—
14.....	—	—	—	—	—	—	—	2
15.....	1	—	—	—	—	—	—	2
17.....	9	31	27	16	10	1	—	2
18.....	4	7	3	2	—	—	—	—
19.....	1	—	—	—	—	—	—	1
21.....	4	—	4	24	—	1	44	86
24.....	1	—	1	—	—	—	—	—
29.....	—	17	1	—	—	—	13	29
30.....	—	1	—	—	—	—	1	7
32.....	—	4	1	—	—	—	3	12
34.....	—	—	—	1	3	7	1	4
36.....	—	—	—	2	—	—	113	217
A.....	—	—	—	—	—	—	—	2
B.....	—	—	—	—	—	—	—	3
C.....	—	—	—	—	—	—	—	19
D.....	—	—	—	—	—	—	—	1
Total number of forms.....	9	10	9	8	5	6	6	15
Total number of collections made in year.....	28	78	44	61	29	39	175	388

TABLE 4

DISTRIBUTION BY PROVINCES OF THE PHYSIOLOGIC FORMS OF *P. graminis Tritici* IN CANADA IN 1927.*
M. NEWTON, T. JOHNSON AND A. M. BROWN, IN REPORT OF DOMINION RUST RESEARCH LABORATORY FOR 1927.

	9	14	15	16	17	21	29	30	32	34	36	B	C	D	E	F
Prince Edward Island.....	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—
Nova Scotia.....	—	—	—	—	—	3	—	1	—	—	3	—	4	—	—	—
New Brunswick.....	—	—	—	—	—	—	—	—	—	—	1	—	2	—	—	—
Quebec.....	—	—	—	—	1	5	—	—	—	—	7	—	—	—	—	—
Ontario.....	—	1	—	—	2	7	—	1	—	1	7	—	1	—	—	—
Manitoba.....	3	6	3	—	8	50	1	4	2	7	78	4	5	6	1	—
Saskatchewan.....	2	—	2	—	7	50	1	2	—	4	83	2	3	—	—	1
Alberta.....	—	1	1	1	2	23	—	—	—	—	45	2	—	—	—	—
British Columbia.....	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—
Total.....	5	8	6	1	20	139	2	8	2	12	225	8	15	6	1	1

*This table is incomplete, representing only rust collections identified up to January 31, 1928.

Total number of forms, 16.

Total number of collections, 459.

For details see the following:—

¹⁰ M. Newton and T. Johnson. Greenhouse Experiments on the Relative Susceptibility of Spring Wheat Varieties to Seven Physiologic Forms of Wheat Stem Rust. Scientific Agr. 7: 5, 1927.

¹¹ Reports on the Uniform Rust Nurseries. In Reports of the Dominion Botanist for the year 1919 to 1928. Dom. of Canada Dept. of Agric.

¹² C. H. Goulden. Report on Varietal Tests. In Reports of the Dominion Cerealists for the years 1926 and 1928. Dom. of Canada Dept. of Agric.

None of these, though, is entirely resistant and each is objectionable for some other reason, chiefly because of the low quality of the flour produced from them. Several highly resistant durum and emmer varieties have been found but these are, of course, useless as bread wheats.

DEVELOPING RESISTANT WHEAT VARIETIES BY PLANT BREEDING

Since none of the existing wheat varieties is satisfactory, it is necessary to develop by plant breeding methods, a new variety which will have adequate resistance to rust and at the same time all those other characteristics of quality, yielding ability, early maturity, etc., which go to make up a satisfactory bread wheat for Western Canada. Two methods of procedure are possible: (1) to cross highly resistant durum and emmer varieties like Iumillo, Pentad, and Khapli, with a high-quality bread wheat like Marquis; or (2) combine the resistance of partially resistant common wheats like Kanred, Kota, Marquillo, H-44-24, etc., by intercrossing these varieties, and build up the quality of the resulting hybrid, if necessary, by further crosses with Marquis.

The first method, of crossing durum and common wheats, appears the most direct, but a large number of investigators^{13, 14} in the United States and Canada have found it impossible to get from such crosses all that they wished in the way of quality combined with rust resistance. Two major difficulties, linkage and sterility, have been encountered. That is, in such crosses the rust resistance of the durum parents has been linked in inheritance with so many other durum characteristics that any hybrids which were highly resistant were like their durum parents in too many other respects to make satisfactory bread wheats. Or, the cross was being made between parents which were so distantly related biologically that the offspring was sterile, or so nearly so that the desirable combinations were lost. The best that has come directly from this type of cross so far has been highly resistant hybrids of medium to low quality, and in no case has the resistance of these hybrids been so great as that of the durum parent from which they came. Durum and emmer common wheat crosses have however made this exceedingly important contribution: they have transferred to common wheat varieties a large measure of the rust resistance which existed previously only in the durum and emmer wheats. That is, they have made possible the second mode of attack on the problem.

The second method of attack is by combining into one variety the resistance of several partially-resistant common wheats. This is the procedure to which most attention is being given at the Dominion Rust Research Laboratory. The three most interesting partially-resistant common wheats are Marquillo, Double Cross Minn 825-2, and H-44-24. All of these varieties are of hybrid origin, the first two having been produced by Hayes and his co-workers at the University of Minnesota, and the third by McFadden of Webster, S.D. From greenhouse tests¹⁰ it is evident that we have in these three varieties resistance to seven of our most commonly occurring forms of rust. The breeding program at this laboratory aims essentially to combine the resistance of these three varieties into one and to raise the quality of that one variety to a satisfactory standard.

In addition to this main project, a number of additional crosses are being carried out between standard varieties like Marquis, Ruby, and Reward, and partially-resistant varieties. From these it is hoped to obtain early-maturing, high-quality varieties with considerable resistance in a much shorter time than it will take to obtain a thoroughly resistant variety by the process indicated. An early variety with considerable resistance would, it is felt, greatly reduce rust losses even if it did not entirely solve the problem.

¹³ Hayes, H. K., E. C. Stakman and O. S. Aamodt. Inheritance in Wheat of Resistance to Black Stem Rust: *Phytopathology* 15: 7, 371-378, 1925.

¹⁴ Thompson, W. P. The Correlation of Characters in Hybrids of *Triticum durum* and *Triticum vulgare*. *Genetics* 10: 285-304, May, 1925.

The development of new varieties by plant-breeding processes requires a long time to produce the desired results. In the first year of the cross the pollen from one parent is mechanically transferred to a certain number of flowers of the other parent which have previously had the pollen-producing organs removed before they were mature enough to produce pollen. Thus the female cells (ovaries) of one parent are fertilized by the male cells (pollen) of the other parent, and the resulting seed has in its make-up the characteristics of both parents. Suppose 50 of such seeds are obtained the year the cross is made. The following year these 50 seeds are planted about 3 inches apart in rows so that each will produce as many seeds as possible that year. All of these 50 first-generation plants will appear identical, and will resemble both parents in many respects. If each of these 50 plants produces 300 seeds, we have the following year 15,000 plants resulting from this cross. In the second year segregation occurs; that is, among the 15,000 second-generation plants we should find all sorts of different combinations of parental characteristics. Among these we choose those combinations which appear to suit our particular purpose and carry these selections along to the next year for still further selection. Four years after the cross is made we will probably have some selected lines which are breeding true for resistance and are therefore satisfactory in that respect. Three additional years will be necessary to test out the other characters—yielding ability, time of maturity, milling and baking quality, etc.—and, by the end of seven years, if everything is satisfactory, the new variety will be ready to increase for distribution. If the new variety is seriously lacking in any particular, it may be necessary to make another cross and repeat the whole procedure. Thus, while the segregation and recombination of characters in a cross take place according to fixed and definite laws of heredity, there are enormous numbers of possibilities, and to select the particular complex that fits your special needs is a matter requiring the greatest care and judgment.



FIG. 16.—An indoor wheat crop. By growing the seeds of crosses in the greenhouse a year is saved.

In 1927 the hybrid nursery at this laboratory included 750,000 individual plants representing 20 different crosses. Among these were several lines of great promise but, since that was only the third year following the cross, a great deal still remains to be done in the way of testing these promising strains. To date, however, the results are distinctly encouraging.

OTHER METHODS OF RUST CONTROL

While the development of resistant varieties is unquestionably the ideal solution to the rust problem, as we have seen, that will probably require several years to accomplish. Therefore any other method of attack on the problem which promises even a measure of relief while resistant varieties are being produced is worthy of serious attention.

DUSTING WITH SULPHUR

Dusting with sulphur unquestionably offers the most promising method of controlling rust aside from the development of resistant varieties. Field results¹⁵⁻¹⁶ for the past three years have demonstrated beyond question that the method is effective even under severe epidemic conditions. Some very



FIG. 17.—The effectiveness of sulphur dusting. The heads in A and B were taken from the same seed lot, sown at the same time. A was dusted with sulphur, while B was not.

For details of these experiments the reader should consult these references:—

¹⁵ D. L. Bailey and F. J. Greaney. Preliminary experiments on the control of leaf and stem rust of wheat by sulphur dust. *Scientific Agriculture* 6: 113-117, 1925.

¹⁶ D. L. Bailey and F. J. Greaney. Dusting with sulphur for the control of leaf and stem rust of wheat in Manitoba. *Scientific Agriculture* 8: 7: 409-432, 1928.

striking results have been obtained from small-plot experiments with sulphur dust. In 1925 the yield was raised from 15 to 55 bushels per acre and the grade from feed to 1 Northern; in 1927 the yield was raised from 10 to 43 bushels per acre and the grade from feed to 1 Northern, in both cases solely through controlling rust by dusting with sulphur. In the face of such results, the effectiveness of the method is no longer open to question.

Whether or not the method can be extended to general practice, without sacrificing its effectiveness and without being too costly, is still a question. The efficiency of the method depends on the toxic effect of sulphur on the germination of the rust spores. If sulphur is present when the spores begin to develop, it quickly kills them. But if the spores germinate and penetrate the plant before sulphur is applied, the fungus is then beyond the reach of external fungicides and develops normally even if sulphur is applied subsequently. It is evident therefore that if rust is to be effectively controlled by sulphur, the crop must be dusted often enough to keep new growth protected and to maintain a



FIG. 18.—Aeroplane sulphur dusting for the control of stem rust. The sulphur is released in the propeller blast. The plane flies from 10 to 20 feet above the crop at approximately 100 miles per hour. Photo. by W. R. Leslie, Experimental Farm, Morden, Man.

continuous coating of sulphur over the older parts of the plants while they are exposed to the attack of rust. That means protecting the crop for a period of from four to six weeks in Western Canada, and this is evidently a large undertaking where the wheat acreage is so enormous and where the value per acre of the crop is too low to permit adding any great amount to the costs of production. Experiments to date indicate that the cost of the sulphur will not be a limiting factor to the usefulness of the method, and that the chief difficulty will lie in the cost of application.

Preliminary field trials, using both aeroplane and horse-drawn field dusters, were carried out in Manitoba in 1927. The horse-drawn field duster did very effective work and resulted in a net profit of \$11.87 per acre from the operation. The chief objection in this case was that the capacity of the machine was too limited to recommend it for large-scale work in general farm practice.



FIG. 19.—Aeroplane sulphur dusting, showing how the dust cloud settles on the crop.

If a satisfactory duster of this type can be developed without too great expense, there seems every reason to hope that this method of rust control would be quite generally applicable and a real service.

Aeroplane dusting gave varying results in different localities, depending largely on local weather conditions, and the rate at which the sulphur was applied. In general, however, it was satisfactory as far as efficiency was concerned, and demonstrated that the aeroplane was well suited to this type of work. Further investigations must be carried out to determine finally the cost of aeroplane dusting before there could be justification for introducing the method commercially.

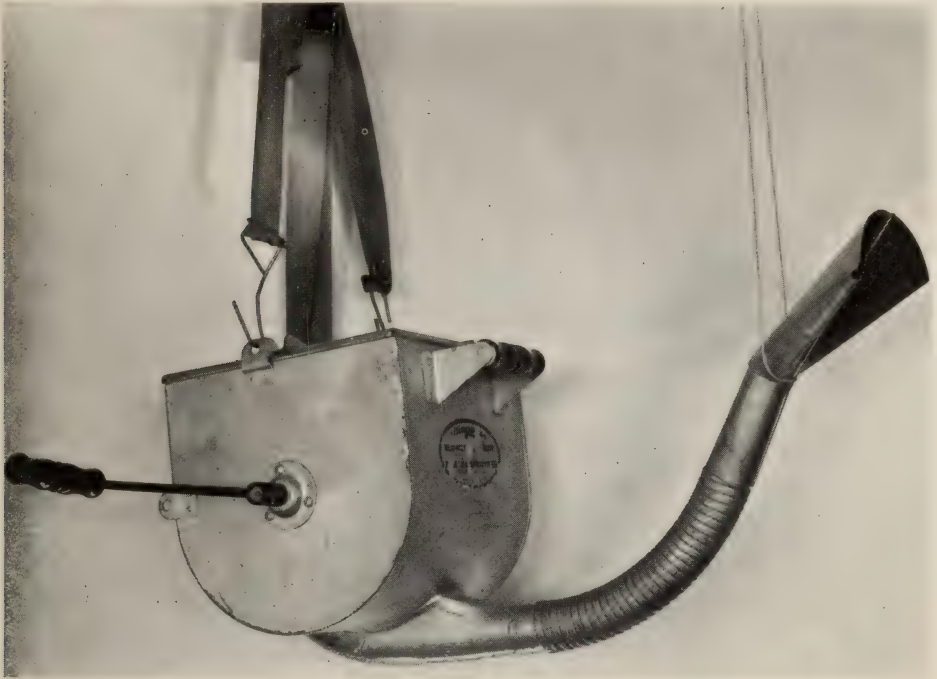


FIG. 20.—Blower dust gun of the type recommended for applying sulphur on small areas for seed or exhibition material.

The value of sulphur dusting for protecting the seed plot or exhibition material from rust is already thoroughly established. A dust gun of the general type indicated in fig. 20 will be found most satisfactory. The plot should be dusted first just as soon as the first traces of rust show up in the district. This should be repeated once per week until the crop begins to mature. Sulphur should be applied at the approximate rate of 30 pounds to the acre and any good grade of dusting sulphur of 300-mesh fineness will be found satisfactory. Ordinary flowers of sulphur is much too coarse. A great deal of dust is wasted with less satisfactory coverage if some kind of duster is not used.

CULTURAL PRACTICES

Cultural practices influence rust development almost entirely by influencing the time at which the crop matures. They should of course be directed to hasten maturity, and anything that does this should be adopted, while anything which delays maturity should be avoided, in so far as such a scheme can be reconciled

with good general farm practice of the particular district concerned. The most desirable procedure will vary somewhat in different districts and this is a matter on which the experienced local farmer will need no guidance. In the Red River Valley and Southern Manitoba costly experience over a period of years has proved without question the undesirability of sowing wheat significantly later than the bulk of the crop has been sown, or in years when the general time of planting falls seriously later than the ten-year average.

PARTIALLY RESISTANT AND EARLY VARIETIES

The superiority of partially resistant varieties over susceptible varieties in yield and grade is not open to question. From the standpoint of production, therefore, it might seem logical to recommend the general adoption of partially resistant varieties. But it must be remembered that profitable production depends on satisfactory marketing of the article produced, and our foreign markets depend very largely on the quality of wheat we produce. Practically all the partially resistant varieties of bread wheat offered to the farmer at the present time are distinctly low-quality varieties. To adopt them generally would be merely easing to a limited extent a problem in production at the cost of creating more serious problems in marketing.

Durum wheats as a class have more resistance to rust than bread wheats. In certain districts, therefore, where standard common wheats cannot be grown profitably because of rust, the adoption of durum varieties is often of distinct advantage. Unfortunately, however, since durum wheats are used almost entirely for macaroni and related products, there is a distinct limit to market requirements for them. If production exceeds that, a serious break in prices will be inevitable.

Early common wheat varieties available at the present time do not compare favourably with Marquis. Prelude and Ruby, for instance, do not yield as well as Marquis, and Garnet does not measure up to it in quality. It is perhaps pointless to make the comparison, since they are chosen only where Marquis cannot be grown to advantage. In many cases, especially perhaps on heavy summer-fallow land which produces too rank and late a stand of Marquis or of durums, these varieties have much to recommend them.

The choice of the most satisfactory variety to be grown in any locality is a local problem which can be solved best by experience. In most cases, no thoroughly satisfactory variety is available at present, and that accounts in a large measure for the multiplicity of varieties now met with, especially in Manitoba. Most of these varieties have little or nothing to recommend them, and regarding them your nearest Agricultural College or Experimental Farm can give you the best available information.

FUNDAMENTAL INVESTIGATIONS

In addition to the work so far reviewed, investigations are in progress at the Rust Laboratory dealing with some problems which will probably already have suggested themselves to the reader. One of these is the origin and constancy of physiologic forms of rust. This has a direct bearing on the plant-breeding work, for it will obviously be impossible to cope with the problem by the relatively slow methods of plant breeding, if existing rust forms change rapidly, or if additional ones are being produced in large numbers.

The constancy of existing forms of rust is a difficult matter to test experimentally. Such evidence as has accumulated from keeping various forms of rust growing in the greenhouse for periods covering several years indicates that the infective powers of a particular rust form remain constant under those con-

ditions. In one case, however, a form of rust suddenly changed¹⁷ from the normal colour to a light orange, and has retained this colour for more than a year. This type of sudden unexplained change resulting in a new fixed condition is called mutation, and this seems to be one means by which new forms of rust may originate from existing forms.

A second way in which new forms of rust may arise has recently been shown by Craigie. He demonstrated¹⁸⁻¹⁹ that the developmental stage of rust on the barberry involves a much reduced but very perfect sexual process and that therefore hybridization, or crossing, of different rust strains is at least a theoretical possibility. At first this seems to present the discouraging possibility of an unlimited number of forms of rust arising through crossing of the forty odd forms now known on the barberry. It must be remembered however that, although it has been discovered only recently, this process has been going on indefinitely and that therefore we may have already all the hybrid forms possible under the circumstances. Or, it may be that among these now known we have the particular combination which produces the maximum virulence possible. Further investigation will be necessary to clear up these points; in the meantime the breeding work should be emphasized as much as possible as the best hope of solving the problem.

The possibility of there being two different types of resistance to the rust organism is another very significant consideration. In most varieties the reaction of the seedling stage to rust is an accurate index of its reaction to the same form of rust throughout all the later stages of its development. There are a few varieties, like Acme, Kota and H-44-24, however, in which this does not seem to be the case. These varieties acquire about heading time a so-called "mature-plant" type of resistance which makes them highly resistant at that time to forms of rust to which they were quite susceptible in the seedling stage. Since rust rarely develops seriously in Western Canada before the crop has reached this stage of development, it appears that this type of resistance would be adequate under our conditions. There are some indications that it may be equally effective against all the different forms of rust and, if this is the case, this should greatly simplify the breeding program. Investigations are being carried on to determine if possible the nature of this resistance and the factors influencing its expression.

STEM RUST OF OATS

Since stem rust on oats is biologically distinct from that on wheat (see page 18), it is evident that the oat rust problem must be approached as an entity and that investigations paralleling approximately those described for wheat rust must be carried on regarding oat stem rust. These are in progress at the Rust Laboratory. To date six physiologic forms of oat rust have been discovered.²⁰⁻²¹ One of these physiologic forms is unfortunately so very virulent that it attacks readily all the varieties which have proved resistant to the other five forms. Fortunately this virulent form is of very limited occurrence and, if this continues, the problem should be solved in a reasonable time by crosses now in progress between resistant and standard varieties of oats. If the virulent form becomes widespread, the problem cannot be solved until varieties resistant to it can be located. Foreign oat varieties in large numbers are being tested in the hope of discovering varieties resistant to this form.

¹⁷ M. Newton and T. Johnson. Color Mutations in *Puccinia graminis Triticum*. *Phytopathology* 17: 10: 711-725. 1927.

¹⁸ J. H. Craigie. Experiments on sex in rust fungi. *Nature* 130: 3012: p. 116. July 23, 1927.

¹⁹ J. H. Craigie. Discovery of the function of pycnia of the rust fungi. *Nature* 130: 3030: Nov., 1927.

²⁰ D. L. Bailey. Physiologic specialization in *Puccinia graminis Avenae*. Univ. of Minn. Agr. Expt. Sta. Tec. Bul. 35. 1925.

²¹ W. L. Gordon. Physiologic forms of Oat stem rust. In Report of Dominion Rust Research Laboratory for 1927.

OTHER CEREAL RUSTS

The occurrence on cereals of rusts other than stem rust often causes a great deal of confusion and popular misunderstanding.

ORANGE LEAF RUST OF WHEAT

In Western Canada the orange leaf rust and black stem rust of wheat are most commonly confused, because they occur together very frequently and are not always easy for the layman to distinguish. Both of these rusts may occur on the leaves and leaf-sheaths of wheat, but only the stem rust is ordinarily found on the stem proper. Where they occur together, they can usually be distinguished by the colour and the type of the rust pustule produced. The leaf-rust pustule is typically orange-coloured and is hence considerably lighter in colour than that of stem rust. Also the leaf-rust pustule usually breaks through the upper surface of the leaf only, while stem-rust breaks through both on the upper and lower surfaces of the leaf, and the pustule is characteristically longer than the rather round pustules of leaf rust. As a final check, these two rusts can be easily separated by examining the spores microscopically, since the two can be separated at a glance by the shape of the spores. Leaf rust, while not nearly so serious as stem rust, does cause appreciable losses²² and undoubtedly contributes its share to the aggregate loss in most of our heavy epidemics.

STRIPE RUST OF WHEAT AND BARLEY

This rust occurs to a limited extent in Alberta on some wild grasses and to a lesser extent on wheat and barley. Although it has been known to occur in Alberta for several years, it does not seem to have found environmental conditions in Western Canada congenial, for there has been little or no tendency for it to spread. It is to be hoped that it remains localized, because this rust is the most troublesome one on cereals in many parts of Europe. It can be distinguished from the other rusts by its light orange colour and by its long stripe-like pustules.

CROWN RUST OF OATS

Next to stem rust, this is the most destructive cereal rust we have in Western Canada. It often occurs in conjunction with oat stem rust from which, however, it is readily separated by its light orange colour. Sometimes, as in 1927, it occurs as a general epidemic like stem rust, but more often it appears as local epidemics of limited extent. These local epidemics usually centre around ornamental or wind-break plantings of the European Buckthorn (*Rhamnus cathartica*), which is the alternate host for this rust, acting in the same way as the barberry does in the case of stem rust. Where local epidemics of this type occur, the buckthorn should be got rid of, authority for doing so in Western Canada being provided for by a recent amendment to the Destructive Insect and Pest Act.

LEAF RUSTS OF BARLEY AND RYE

A leaf rust caused by *Puccinia anomala* occurs rarely on barley and one caused by *Puccinia dispersa* occurs commonly on rye in Manitoba. Neither of these rusts appears to have any appreciable economic significance.

²² C. H. Goulden. A statistical study of the characters of wheat varieties influencing yield. Scientific Agriculture 6: 10: 337-345. 1926.

SUMMARY

1. Stem rust is the most serious problem in cereal production in Manitoba and Saskatchewan to-day. It has caused an average annual loss during the last twenty years of at least 25 million dollars. The most serious epidemic occurred in 1916, when an estimated loss of 200 million dollars was sustained. Less serious epidemics occurred in 1904, 1909, 1919, 1925, and 1927.

2. Rust is caused by a fungus parasite which is called *Puccinia graminis*. The life history of this organism is described and the factors which influence its development are discussed.

3. The origin and spread of stem rust in Western Canada is discussed. Barberries appear to have little significance in this respect here and the uredinial or summer stage apparently does not survive over winters except perhaps in rare isolated instances. The results of field surveys correlated with studies of the rust-spore content of the air indicate that our earliest infections each year are due to wind-borne rust spores from farther south in the spring wheat area. Rust appears first in the south and spreads northward and westward across the prairie provinces.

4. The development of rust-resisting wheat varieties of satisfactory quality is the ideal and the most promising hope of solving the rust problem.

Twenty-five different forms of wheat stem rust have been found in Canada. These appear identical even under the microscope but differ from each in their powers of infecting twelve differential wheat varieties. Usually one or two forms of rust occur very commonly and a few more occur less commonly in any particular year. The forms which predominate change from year to year.

None of our standard wheat varieties is resistant to anything like all the forms of rust which occur commonly in Western Canada. In general those varieties which have proved partially resistant have proved poor in quality. Satisfactory varieties therefore must be developed by plant-breeding methods.

The plant-breeding program at the Dominion Rust Research Laboratory aims essentially to build up adequate resistance by intercrossing several partially resistant varieties and to improve the quality of the resulting hybrids to a satisfactory standard. About twenty different crosses are being carried on, some of which are now in the fourth generation. To carry this program through to completion will require several more years of work.

5. Next to the development of resistant varieties, dusting with sulphur offers the greatest hope of controlling rust. It has proven effective, but further investigations are necessary to devise a satisfactory method of applying the dust effectively and economically on large acreages.

6. Where Marquis wheat can no longer be grown with profit because of rust, a farmer will be well advised to try either a variety which matures earlier than Marquis or a durum variety. Consult your nearest Experimental Farm or Agricultural College before adopting new varieties. Many of these new varieties have nothing to recommend them.

7. Oat stem rust is distinct biologically from stem rust of wheat. Six forms of oat stem rust have been found and crosses are being carried out to develop resistant varieties of high quality.

8. A number of cereal rusts other than black stem rust which occur in Canada are briefly described.



STUDIES IN CEREAL DISEASES PREVIOUSLY ISSUED:

- I. Smut Diseases of Cultivated Plants, Their Cause and Control—by H. T. Güssow and I. L. Conners (Bulletin 81, New Series), 1927.
- II. Root Rots and Foot Rots of Wheat in Manitoba—by F. J. Greaney and D. L. Bailey (Bulletin 85, New Series), 1927.
- III. Seedling Blight and Foot Rots of Oats caused by *Fusarium culmorum* (Wm. G. Sm.) Sacc.—by P. M. Simmonds (Bulletin 105, New Series), 1928.

